J.Korean Asso. Radiat. Prot.
Vol.26 No.3 : 287-290(2001)

SEPARATION OF GAMMA-RAYS PRODUCTION FROM $^{13}C(p, \gamma)^{14}N$, $^{14}N(\gamma, \gamma)^{14}N$ REACTIONS USING DOPPLER SHIFT EFFECT

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Abstract - The 9.17MeV gamma-rays from the $^{13}C(p,\gamma)^{14}N$, $^{14}N(\gamma,\gamma)^{14}N$ reactions were measured. The incident 9.17MeV gamma-ray was produced from the $^{13}C(p,\gamma)^{14}N$ reaction at Ep=1.75MeV resonance. The 1.75MeV proton beam was accelerated using the 3MV SNU-AMS Tandetron and 1.7MV KIGAM Tandem accelerators. The enriched 13C target was 121 $\mu g/cm^2$ self-supporting foil, and we used liquid nitrogen as a resonant absorption target. We used a HP-Ge detector with 30% efficiency and less 2keV energy resolution. We developed new method to detect the scattered 9.17MeV gamma-ray from the nitrogen target by using the energy difference between the Doppler shifted gamma-ray from the $^{13}C(p,\gamma)^{14}N$ reaction and the resonant absorbed and rescattered gamma-ray from the $^{14}N(\gamma,\gamma)^{14}N$ reaction.

INTRODUCTION

A new landmine and explosive detection technique is to detect the nitrogen nucleus directly by using the photo-nuclear resonant reaction $^{14}N(\gamma,\gamma)^{14}N$. The photo-nuclear resonance gamma-rays are produced by nuclear reactions $^{13}C(p,\gamma)^{14}N$, in which ^{13}C target is bombarded by a 1.75MeV proton beam extracted from the proton accelerator. To avoid other neighboring resonant gamma-rays, we selected a higher resonant energy of 9.17MeV. The 9.17MeV gamma rays produced are absorbed or scattered when they react with ^{14}N nuclei included in the landmines and explosives. We can determine existence of mines or explosives by measuring the absorption and scattering of gamma-rays.

Several methods of mine and explosive detection were suggested, for example, NQR (nuclear quadrupole resonance), metal survey meter and so on. However, while applied to anti-personal mine which dose not contain any metal components, a conventional method based on metal survey is not effective. NQR method is deeply dependant on the large electric quadrupole moment comparing with other stable element under ground, and it was known that NQR detection frequency varied as a chemical composition and temperature.

In the study of explosives detection, we have surveyed the various present technologies and the requirements. The explosive detector based on the gamma resonance reaction should be relatively superior to the present ones in accuracy. The gamma resonance scattering in ^{14}N rich compounds was verified successfully by using a Tandem accelerator at low beam current. But for the verification of the field application, a higher beam current over 10mA is needed.

The major difficulty is that the energy of the absorbed and re-emitted gamma-rays from $^{14}N(\gamma,\gamma)^{14}N$ reaction is almost same with that of the target gamma-ray from $^{13}C(p,\gamma)^{14}N$ reaction. An over 30 cm thick Pb shield is needed to overcome the ^{13}C target gamma-ray yield, and it is a big burden for the system designer as a movable machine. The main goal of this work is to confirm our new detection mechanism in principle by performing a basic nuclear resonant reaction experiment using the Doppler shift effect of gamma-rays produced from $^{13}C(p,\gamma)^{14}N$, $^{14}N(\gamma,\gamma)^{14}N$ resonant reactions.

ESTIMATION AND CALCULATION

Before performing experiment, we have done an estimation calculation for our new detection principle. The properties of a 9.17MeV gamma-ray production ^{13}C target by 1.75MeV proton are summarized as that natural abundance is 1.11%, J^{π} is 1/2-, density is 2.253 g/cm^3, dE/dx = 35.69 MeV/mm, and range is 30.02μm. The range and stopping power is calculated by TRIM code. The resonance width was reported as Γ=122eV and Γ_{γ}=6.3eV [1] , and the calculated thick target yield as 0.64$\times 10^{-8}$ [γ/p]. However, it does not consistent with each experimental data.

The 9.17MeV production yield as a unit of [γ/p] are varied with respect to several experiments, so in the simulation we used 0.88(21) $\times$ 10^{-8} [γ/p], which was obtained from average of some previous experiments, 0.74 $\times$ 10^{-8} [2], 1.01 $\times$ 10^{-8} [3], 1.01 $\times$ 10^{-8} [4] and 0.63 $\times$ 10^{-8} [5]. The underground condition was assumed as attenuation coefficient (=0.0289/cm, and explosive part of anti-personal mine dimension is that 1.5 cm or 5 cm radius and 1cm or 5cm height with a density of ^{14}N element 0.5 g/cm^3.

EXPERIMENT

Experiments were performed several times by using KIGAM 1.7MeV Tandem and SNU-AMS 3MeV Tandetron accelerators. The main experiments were performed using SNU-AMS Tandetron. Firstly, we reviewed previous experiment by using the NaI(Tl) detector with anti cosmic ray shielding by the thick plastic detectors. We used BGO scintillator to increase detection yield than NaI(Tl) scintillator. At least 30 cm Pb shield was required to distinguish the real signal of mines from observed signals.

The protons were accelerated to be 1.75MeV, and then the excitation function, the angular distribution(Fig. 1), the photo-absorption(Fig. 2), and the scattering were measured. The proton Beam Current was over 1μA, and bombarded on a enriched ^{13}C target foil(99%) with 121 μg/cm^2 thickness. The detectors were 3″(3″ NaI(Tl) and BGO scintillators and 2″(3″ HP-Ge detector with BGO Anti-Compton Shields. The mine/explosive emulator was 10cm, 20cm thick melamine or liquid nitrogen.

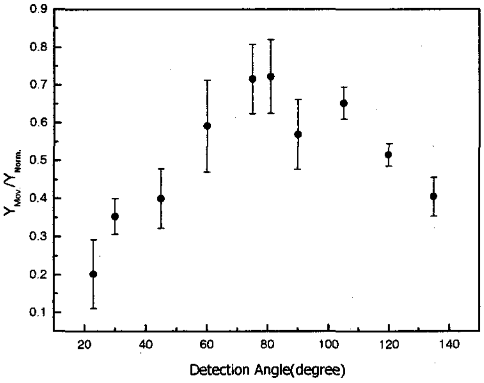

Fig. 1. The angular distribution of 9.17 MeV gamma-rays.

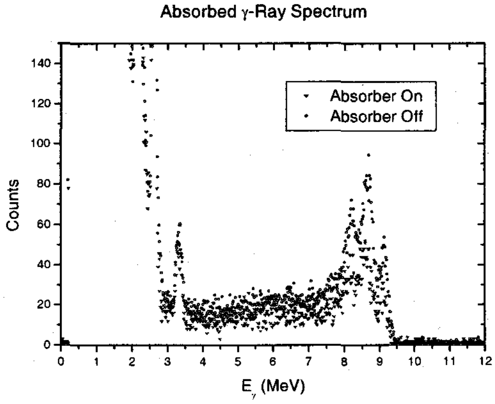

Fig. 2. Resonant absorption reaction spectrum for the melamine

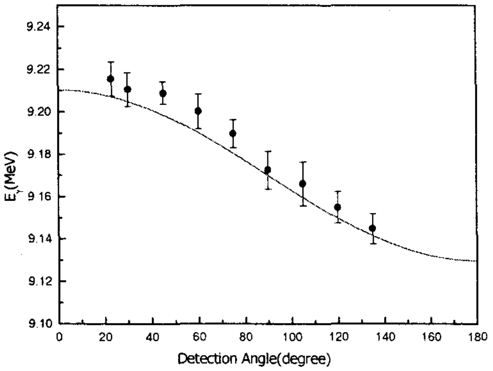

Fig. 3. Doppler effect due to the velocity of compound nucleus. The solid line is a calculated result for the ^{13}C(p,γ)^{14}N reaction at 1.75 MeV proton energy.

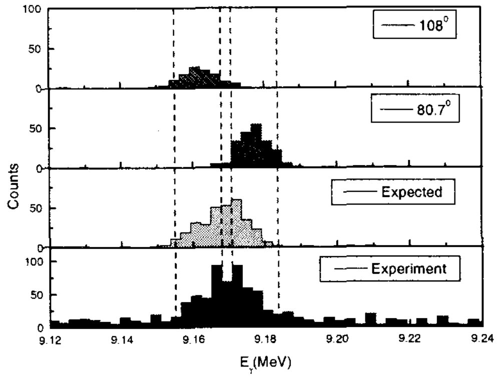

Fig. 4. The spectra measured for the photo-nucleus resonant reaction. Spectrum at 108° is measured at an off-resonance angle and spectrum at 80.7° is at an on-resonance angle.

There is an energy difference between the Doppler shifted gamma-ray from the ^{13}C(p, γ)^{14}N reaction and the resonant absorbed and scattered gamma-ray from the ^{14}N(γ,γ)^{14}N reaction, especially for 9.17MeV resonance state gamma-ray. The Doppler shift effect as a function of detection angle with respect to a proton beam is shown in Fig. 3. The solid line is the calculated result.

We also developed new detection technique to detect the scattered gamma-ray from the nitrogen target by using the energy difference between the Doppler effected gamma-ray from the ^{13}C(p,γ)^{14}N reaction, and the resonant absorbed and scattered gamma-ray from the ^{14}N(γ,γ)^{14}N reaction, especially, 9.17MeV resonance state gamma-ray. In this experiment, we used liquid nitrogen 20l as a resonant absorption mine/explosive emulator. We used a HP-Ge detector with 30% efficiency and less 2keV energy resolution. Fig. 4 is the observed spectrum near single escape peak region.

DISCUSSION

The resonant gamma-ray production yield of the thick target with 121μg/cm^2 is maximized near 1.745MeV, which is agreed well with previous result [1]. The derived resonant width from the experiment is 600eV of FWHM, and the compiled data is about 120eV [1]. However, the width data are not consistent with each other, and depend on the experimental method.

Even though the detection system based on the BGO scintillator has much more yield about 100 times than that on the HP-Ge detector, we want to prove our principle by using Doppler shift effect. So we made a new system based on a HP-Ge detector, which guaranteed 2keV energy resolution at several MeV energies. This system did not need any shield in principle, but when performing experiment 10cm Pb brick was used between ^{13}C target and HP-Ge detector. The major merit of this system is that we can separate the gamma-ray from ^{13}C and mine/explosive emulator when we choose detection angle of mine gamma-ray properly. This method is deeply related on the Doppler effect, because the gamma-ray energies come from ^{13}C target are a function of detection angle, and the gamma-ray energy from mine emulator is the resonant energy with a small recoil correction energy, about 6 keV in this ^{14}N(γ,γ)^{14}N reaction. Such gamma-ray energy deviation is maximized when the detection angle is far from resonant angle.

The gamma-ray production and absorption process are the inverse mechanism, and the available angle of this mechanism is only 80.7° (0.7). This phenomenon results in the Doppler shift effect from the reaction kinematics. The difference from Doppler shift effect between forward and backward detection angle is about 130 keV. We also measured the angular distribution of the gamma-ray production by using the SNU-AMS tandetron accelerator. We used two HP-Ge detectors, in which one was used for the movable angular detector and the other was used for the normalization detector. Fortunately, the yield shows a maximum at the detection angle 90° near resonant angle and the symmetric yield distribution.

The scattered gamma-ray yield from $^{14}N(\gamma,\gamma)^{14}N$ resonant reaction is somewhat less than the expected yield calculated by using previous data. The measured scattered yield is 1.8(0.4)/sec/10mA and the expected one is 4.2(2.5)/sec/10mA. When we calculated the yield, some assumptions were used that thick target yield is 1×10^{-8} γ/p, HP-Ge detector absolute efficiency is 0.1% for the 59.2 mm(diameter) (76.2mm(length) detector crystal dimension, the attenuation is 30% due to liquid nitrogen Dewar[6].

CONCLUSIONS

In the present work, we measured resonant energy and angular distribution, and photo-nucleus *resonant gamma-rays from the* $^{13}C(p,\gamma)^{14}N$, $^{14}N(\gamma,\gamma)^{14}N$ reactions by using HP-Ge, BGO and NaI(Tl) Detectors. We proved new detection principle and observed the scattered gamma-ray by using new method based on energy difference originated from Doppler shift effect. We have plans for further experiment at SNU-AMS facility to confirm and collect a meaningful physical nuclear data. The experimental setup will be a detector system shielded to suppress cosmic ray and gamma-ray from target, including an angular positioning system. The proton beam current will be larger than 10μA. We will improve our data quality as a *nuclear data point of view.*

ACKNOWLEDGEMENTS

This work has been carried out under the nuclear research and development program supported by the Ministry of Science and Technology of Korea.

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